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HIGH VOLTAGE, LOW INDUCTANCE HYDROGEN THYRATRON STUDY PROGRAM, --ETC(U)
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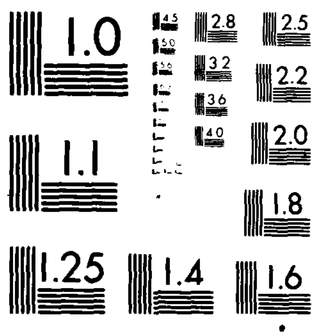

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Research and Development Technical Report
DELET-TR-79-0283-F

HIGH VOLTAGE, LOW INDUCTANCE HYDROGEN THYRATRON STUDY PROGRAM, PHASE III

AD A110132

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December 1981

Final Report for the Period 4 March 1980 — 3 September 1980

DISTRIBUTION STATEMENT: Approved for Public Release; Distribution Unlimited

Prepared for:
Electronics Technology & Devices Laboratory

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DELET-TR-79-0283-F	2. GOVT ACCESSION NO. AD-A110132	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) High Voltage, Low Inductance Hydrogen Thyratron Study Program, Phase III		5. TYPE OF REPORT & PERIOD COVERED Final 4 Mar 80 - 3 Sep 80
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. F. Caristi S. Friedman		8. CONTRACT OR GRANT NUMBER(s) DAAK20-79-C-0283
9. PERFORMING ORGANIZATION NAME AND ADDRESS EG&G, Inc. 35 Congress Street Salem, MA 01970		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62705A 1L1 62705 AH94 02
11. CONTROLLING OFFICE NAME AND ADDRESS Electronics Technology and Devices Lab.(ERADCOM) ATTN: DELET-BG Fort Monmouth, NJ 07703		12. REPORT DATE December 1981
		13. NUMBER OF PAGES 25
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Thyratrons
High Voltage Components
Pulse Modulators
Pulse Generators

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The experimental tube required under the terms of this contract has been designed, built and characterized for voltage holdoff under pulsed charge conditions. This tube (Type HY-5527) exhibited a total holdoff characteristic that was somewhat inferior to that of its predecessor - Type HY-5525. The difference is believed to be attributable to the first-stage holdoff of the HY-5527 which was low compared with that of the HY-5525. Arc damage during conditioning is proposed to account for the HY-5527's poorer first-stage holdoff.(continued)

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Data are also shown for the Type HY-5553, a three-stage device designed and built under a subsequent phase of the overall program. This tube exhibited a total holdoff characteristic that exceeded those of both the HY-5525 and the HY-5527 in the high pressure regime - the region of interest.

Future plans call for further testing of the HY-5553 and another tube of a differing design that appears promising. On the basis of these tests another generation of tubes will be designed, built and characterized at high pulse repetition rates and high rates of anode current rise.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1 PREFACE

This document constitutes the final report due under ERADCOM Contract DAAK20-79-C-0283, otherwise known as Phase III of the High Voltage, Low Inductance Hydrogen Thyratron Study Program. The scope of Phase III was limited to EG&G's building and delivering to ERADCOM a low inductance, multi-stage thyratron representative of the then-current state of the art; no supporting R&D or testing of the prototype tube was expected or funded. For the sake of completeness, however, we have included in this document the results of our conditioning of the tube, together with certain other experimental results and supporting information that bear on the progress of the Program as a whole.

The Government's Contract Monitor for Phase III was Mr. William Wright of ERADCOM. Mr. Robert F. Caristi was EG&G's Program Manager and Dr. Steven Friedman was the Program Engineer.

2 BACKGROUND

The High Voltage, Low Inductance Hydrogen Thyratron Study Program is directed toward the development of a 250 kV thyratron capable of delivering a current pulse of tens of kiloamperes with a rise time of the order of 10 nS. Phase I of the program was a feasibility study,* Phase II included further theoretical studies supported by experimentation,** and Phase III entailed the construction and delivery of a representative device. Phase II also included the delivery of an experimental tube, and a five-stage low inductance device bearing Type Number HY-5525 was in fact delivered to ERADCOM.

The HY-5525 is shown (in section) in Figure 1. The tube had four box-type gradient grids and nominal electrode spacings (E-E) that varied from 121 mils for the first gap to 115 mils at the fifth. The grids had annular slots, 125 mils wide, through grids 150 mils thick. The rationale for the design of this tube is set forth in the Appendix to this report.

The dynamic breakdown characteristic obtained for the HY-5525 before its shipment to ERADCOM is shown in Figure 2. In general the tube performed well, and the data were limited to 70 kV only by the characteristics of the pulse charge test kit. Rise time data were not generated for the HY-5525.

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*R&D Technical Report DELET-TR-77-2725-F, March 1979.

**R&D Technical Report DELET-TR-78-2977-F, January 1981.

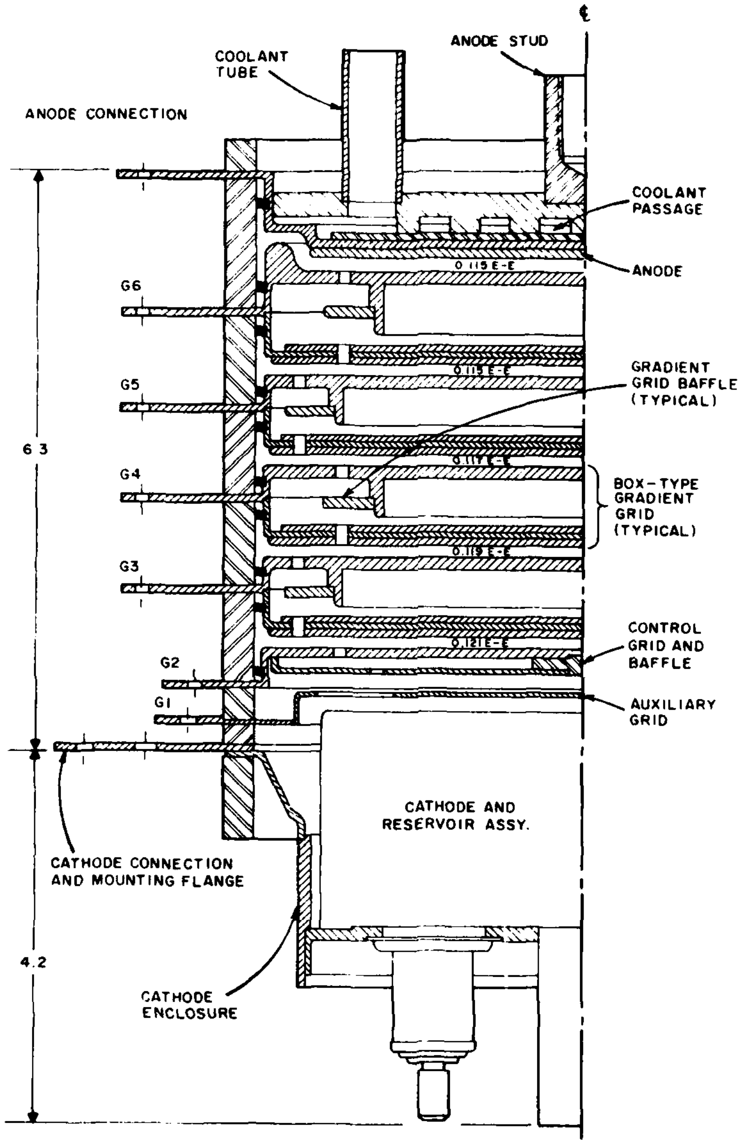

Figure 1. Section drawing showing the salient features of the HY-5525. The gradient grids had annular apertures 125 mils wide. The design of the HY-5527 was identical to that shown above except that two additional gradient grids were used to yield a seven-gap tube. The gap spacings for the HY-5527 were (in order from the control grid to the anode): 121,119,119,119,117,117, and 115 mils.

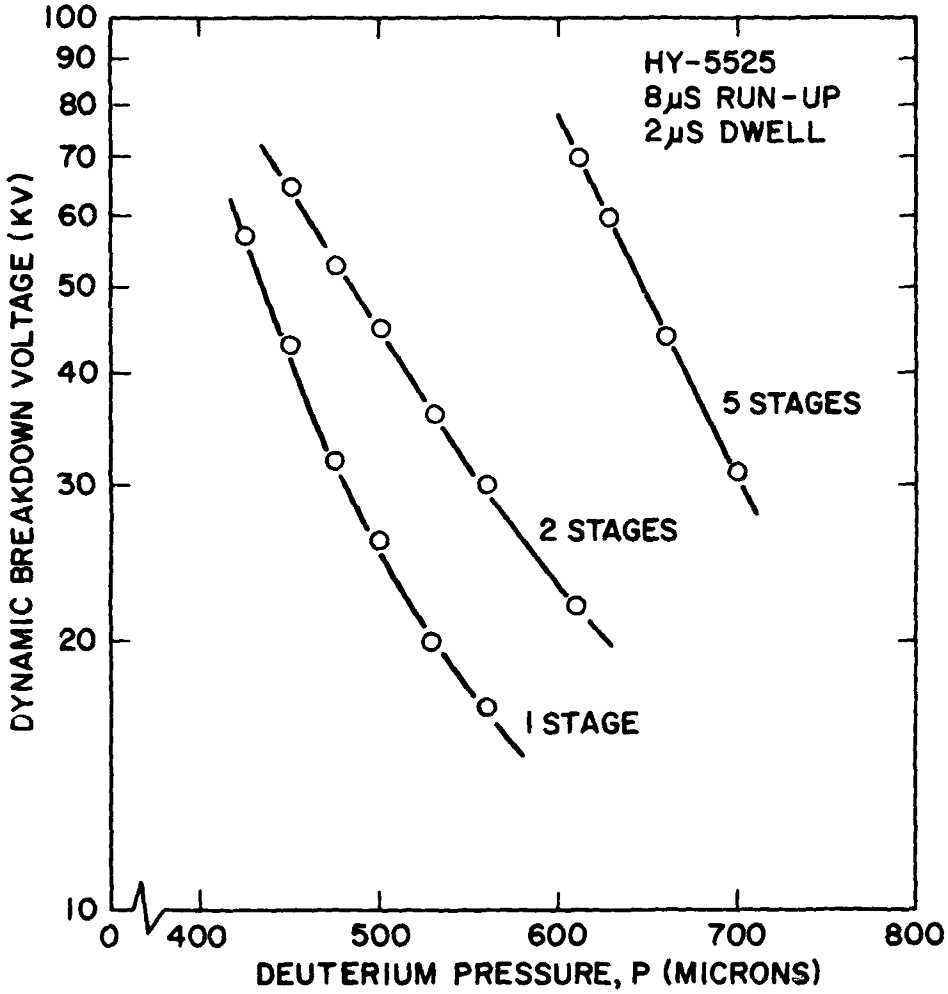

Figure 2. Dynamic breakdown characteristic of the HY-5525. The tube showed good stage voltage addition and substantial total holdoff at high gas pressures.

3 CONDITIONING DATA: HY-5527

The tube delivered under Phase III bears Type Number HY-5527. This tube is in essence identical to Type HY-5525 except that it has two additional gradient grids, for a total of seven gaps. The gap spacings are (in order from the control grid to the anode): 121,119,119,119,117,117, and 115 mils. The pressure characteristic of the HY-5527 is shown in Figure 3, and its dynamic breakdown characteristic is presented in Figure 4.

In general, the performance of the HY-5527 was disappointing, as a comparison of the curves of Figures 2 and 4 shows. The stage voltage addition of the HY-5527 was good, but its first stage could not be conditioned to the holdoff attained for the first stage of the HY-5525. At a representative pressure of 450 microns, the first stage of the HY-5525 held off 43 kV, whereas that of the HY-5527 held off only about 16 kV. As a result of this poor first-stage holdoff, the total holdoff of the HY-5527 was in general poorer than that of the HY-5525. The reason for the HY-5527's poor first-stage holdoff is not known; not only is it poorer than the HY-5525's, it is poorer than that of most of our multi-stage tubes. We suspect that during the conditioning process, a repetitive arc formed in the first stage that has since served to limit its performance.

The anode current rise time of the HY-5527 was measured at a pressure of 680 microns and found to be 12 nS (10% - 90%, 3 kA current pulse). (See Figure 5.) The delay time jitter was found to be 10 nS with 100 mA of keep-alive current applied to the auxiliary grid and a 5 kV, 50-ohm trigger applied to the control grid. Under these conditions, the anode delay time was several hundred nanoseconds. Such measurements could not be taken at materially lower gas pressures because the minimum anode voltage for conduction then exceeded the capabilities of our low inductance test kit.

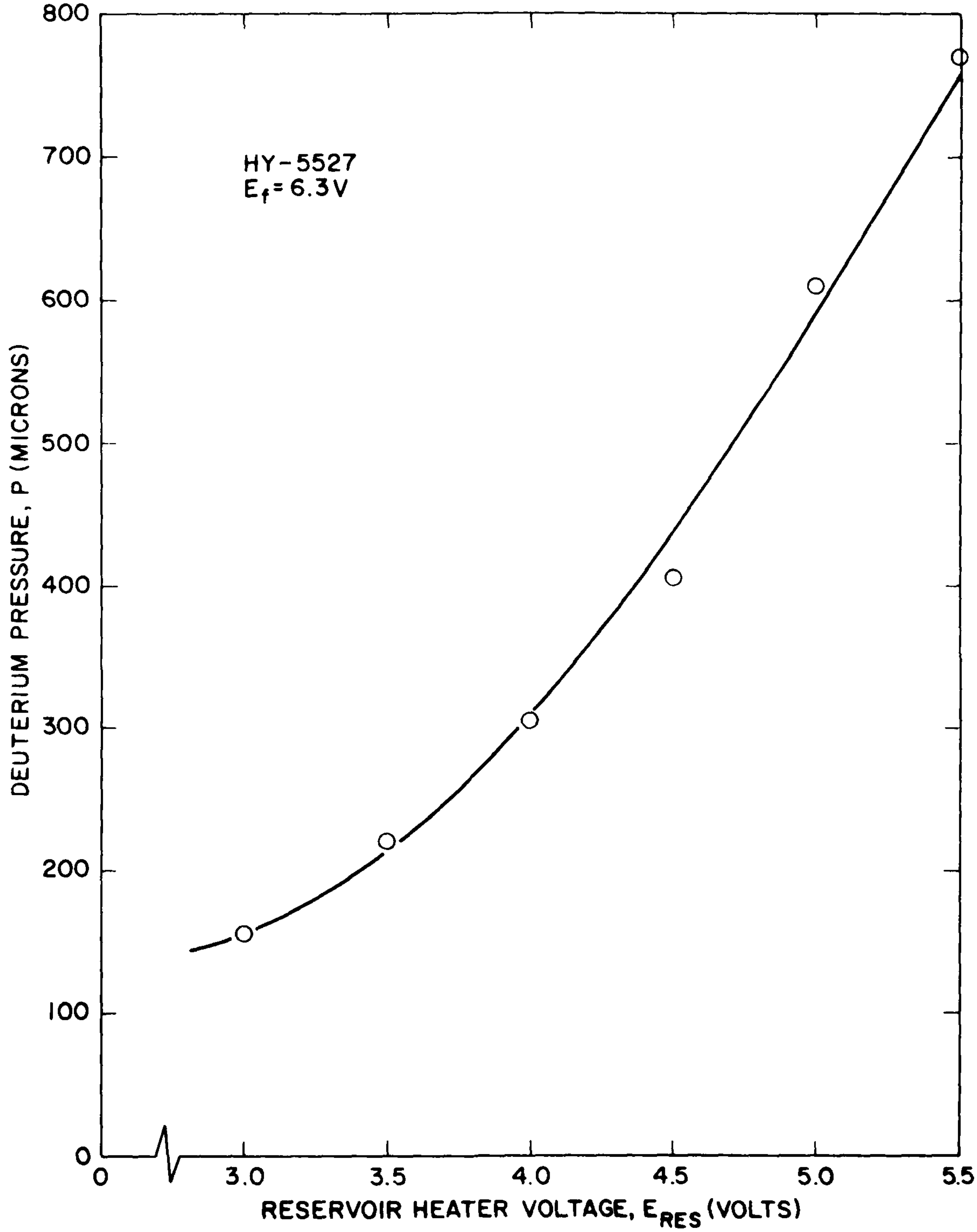

Figure 3. Pressure characteristic of the HY-5527. The tube had been filled with 400 microns of deuterium at E_{res} = 4.5 volts.

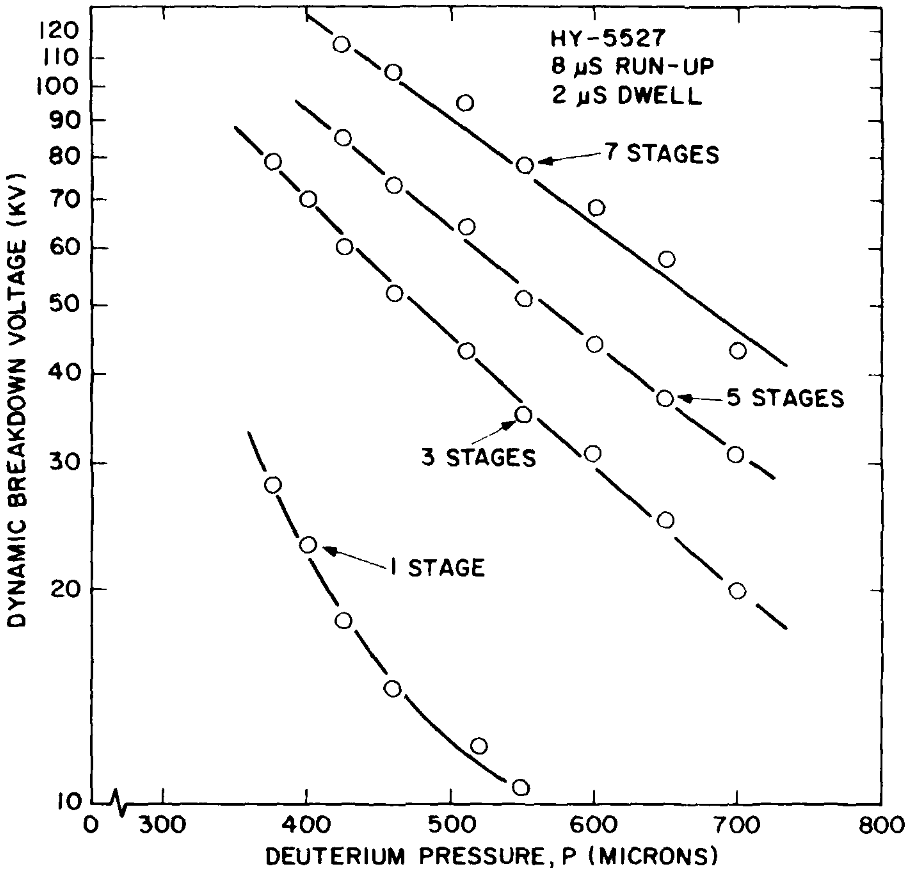

Figure 4. Dynamic breakdown characteristic of the HY-5527. The lower stage holdoff limited the holdoff of the tube as a whole.

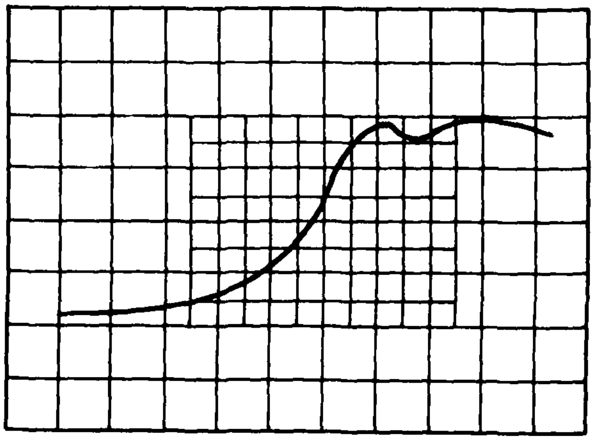

Figure 5. HY-5527 anode current rise at a deuterium pressure of 680 microns. The sweep speed is 2 nS per minor division. The rise time is about 12 nS for the 3 kA current pulse shown.

4 COMPARATIVE DATA: HY-5525, HY-5527, HY-5553

Pursuant to the initial development work funded by ERADCOM, work on the High Voltage, Low Inductance Hydrogen Thyratron Study Program continued under the auspices of the Naval Surface Weapons Center. The object of this work was to extend the results of the ERADCOM Program to yet higher voltages, and to do so with tube geometries that were capable of operation at high pulse repetition rates. Several designs were developed and evaluated using computer field plotting techniques; two were selected as being the most promising, and a representative of each was built. The first of these to be completed bears Type Number HY-5553; initial holdoff data for this tube are shown in Figure 6 together with representative data for Types HY-5525 and HY-5527.

Note from Figure 6 that although the HY-5553 is only a three-stage tube, its total holdoff exceeds that of five stages of the HY-5527, and in the high pressure regime (the region of interest), its holdoff exceeds that of the HY-5525. We attribute the superior performance of the HY-5553 to its smaller electrode spacing (102 mils vs. an average of 118 mils for the HY-5525 and HY-5527) and also to its narrower grid slots (80 mils vs. 125 mils). The HY-5553 also has an extra cathode baffle to shield the first stage from cathode by-products. At the time of this writing, the HY-5553 holdoff data shown in Figure 6 are the only data in existence for this tube, but the tube is conditioning easily, and we expect even better ultimate holdoff than that shown in Figure 6.

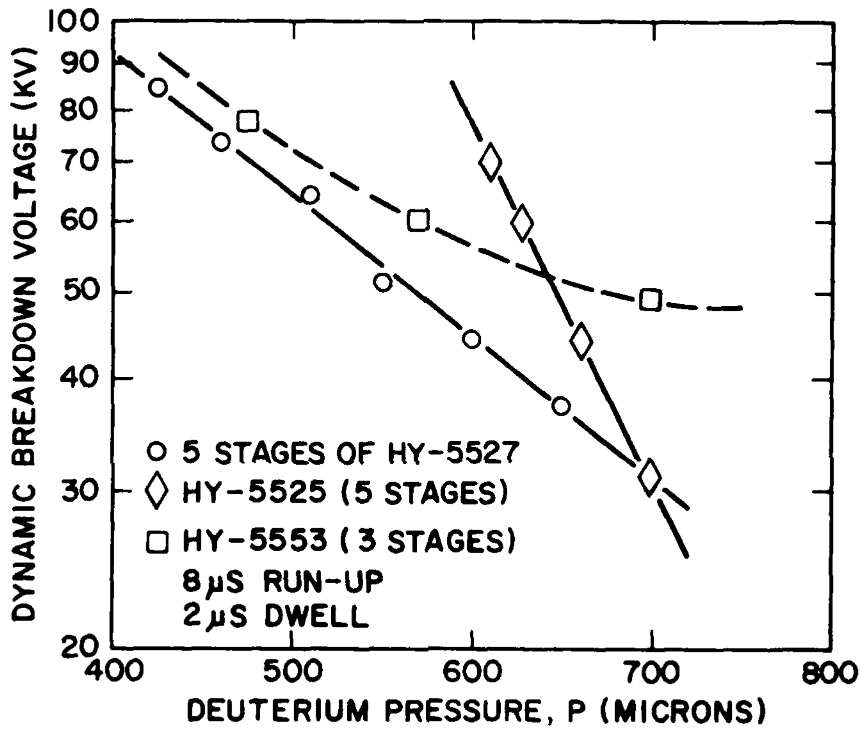

Figure 6. Dynamic breakdown characteristics of various low inductance types. The high pressure holdoff of the three-stage HY-5553 exceeded that of Types HY-5525 and HY-5527.

5 SUMMARY AND PLANS FOR FUTURE WORK

At the beginning of Phase I, the proposition of a 250 kV, 10 nS thyratron switch seemed far removed from reality. The feasibility of such a device has, however, been established, and design techniques have been developed such that 100 kV, 20 nS tubes are now routinely designed and built. Of the two experimental tubes built for ERADCOM, the HY-5525 proved to be the better performer owing to its superior first-stage holdoff. The first-stage holdoff of the HY-5527 was not only poorer than that of the HY-5525, but poorer than that of most multi-stage, low inductance types. We suspect that this stage suffered arc damage during the tube's conditioning. Both the HY-5525 and the HY-5527 exhibited good stage voltage addition.

Work has continued on the Program under the direct auspices of the Naval Surface Weapons Center, and two additional experimental tubes have been designed and built. The initial holdoff data for the first of these, Type HY-5553, indicate that the average high-pressure holdoff (per stage) of the newer design far exceeds that of the earlier series of tubes.

We plan to characterize the newer designs with respect to stage voltage addition, total holdoff, anode current rise time, anode delay time and delay time jitter, and finally, holdoff recovery time. The design offering the best compromise among these characteristics will then be refined and scaled to a sufficient number of stages to hold off 250 kV in the high pressure regime. Tubes of this genre will then be built and characterized at high pulse repetition rates and high rates of anode current rise.

APPENDIX
DESIGN CRITERIA, HY-5525

For the intermediately sized experimental tube delivered to ERADCOM, a conservative design based on the experimental results of Phase II was chosen. The goal was to demonstrate a peak forward holdoff capability arbitrarily chosen to be 150 kV with a tube that operated at high pressure (for a short "resistive" fall time) and had an inductance of less than 50 nH. At lower pressures (but still high by thyratron standards), a peak forward holdoff well in excess of 150 kV was expected. The intermediate tube was designated HY-5525.

The tube envelope was 4.5 inches in diameter, and the tube stood 6.3 inches high from the bottom of the cathode flange to the top of the anode flange. It had five gaps, since 30 kV per stage (on average, and at high pressure) was considered reasonable in light of previous experiments, and yet the combined length of the high voltage sections was short enough to provide a low total inductance. The tube was designed for use with a 12-inch diameter current return. The inductance of the tube/return combination was expected to be about 40 nH.

The design approach was conservative in that only concepts that had been experimentally verified were used. For example, liquid cooling of the anode was provided, but the use of a hollow anode was avoided since experience with such anodes was limited. The gap spacing was varied from 0.121 inch at the control grid to 0.115 inch at the anode to improve the voltage distribution across the tube, but even the 0.115-inch gap was well above the spacing (0.090 inch) where experimental results had shown that field emission might become a concern.

The upper-stage insulator was 1.515 inches long. This was more than adequate according to the results of prior ceramic breakdown tests. The stress during commutation was expected to be only one-third greater than the corresponding stress of earlier designs.

The ratio of gradient grid baffle thickness to internal gradient grid height was chosen to be consistent with that of earlier tubes that had been shown to commutate without difficulty. Reasonably good stage isolation without triggering problems was therefore expected.

Finally, it was decided to offset the apertures from grid to grid but not within each grid, despite computer studies which had shown that the latter technique would be satisfactory. This decision was made because the existing experimental data applied for the prior grid arrangement, while the theory had yet to be experimentally verified.

Some concessions were made in the design of the HY-5525 for the sake of expediency. For example, high di/dt experiments with standard HY-5313's at ib = 10 kA had shown that a short, vertically vaned cathode would ultimately be required for high voltage, low inductance tubes. Specially shaped insulators might allow higher holdoff per stage and promote longer tube life, and a thick, hollow anode will probably be required to provide reasonable life at high anode currents. Finally, improved gradient grid baffling techniques will probably be required to achieve operation at pulse repetition rates beyond about 1 kHz. None of these features were incorporated into the HY-5525. Nonetheless, the building and testing of a high voltage tube that extended previous work and demonstrated high voltage holdoff and low inductance was considered to be an important step toward achieving the objectives of the Program.

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